The Role of Convection in Troposphere-Lower Stratosphere Interactions in Radiative-convective Equilibrium Simulations

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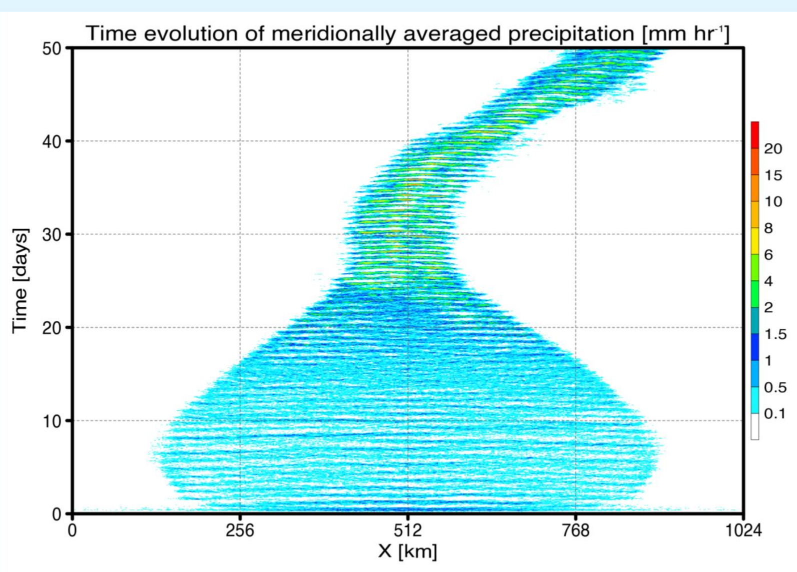
Abstract

This study investigates interactions between the lower stratosphere and troposphere in the idealized Radiative-Convective Equilibrium (RCE) simulation using the Vector Vorticity cloud-resolving Model (VVM). We conducted a long-term RCE simulation with an elongated domain size and high resolution for two years. This allows for a comprehensive analysis of the relationship between domain-averaged zonal wind oscillations and different convective structures. The oscillation is observed to be asymmetric in the first three cycles and symmetric in the last two cycles. The differences in convection structures are found: squall-line-like convection and aggregated convection. The results show that the aggregated convection has more convective core clouds than squall-line-like convection, leading to a faster transition of QBO-like oscillation. In conclusion, this study provides new insight into the impact of different convective structures on QBO-like oscillation.

1. Motivation

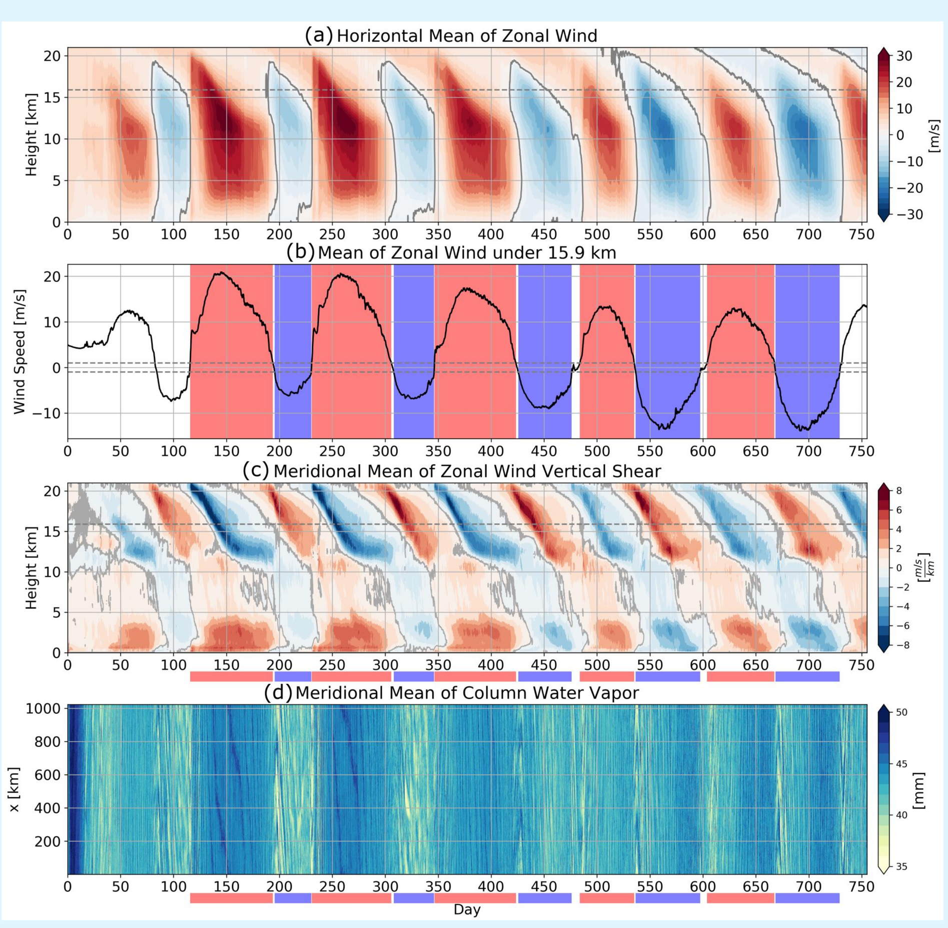


An eastward-propagating aggregated convection is found in the RCE simulation using VVM. In the 50-day simulation, the initiation of a QBO-like oscillation can be observed, which suggests potential influences from the lower stratosphere on the simulated convective processes. Therefore, we conduct the simulation following Yoden et al. (2014) to investigate QBO-like oscillation and its interactions with convection in VVM.

2. Experiment Design

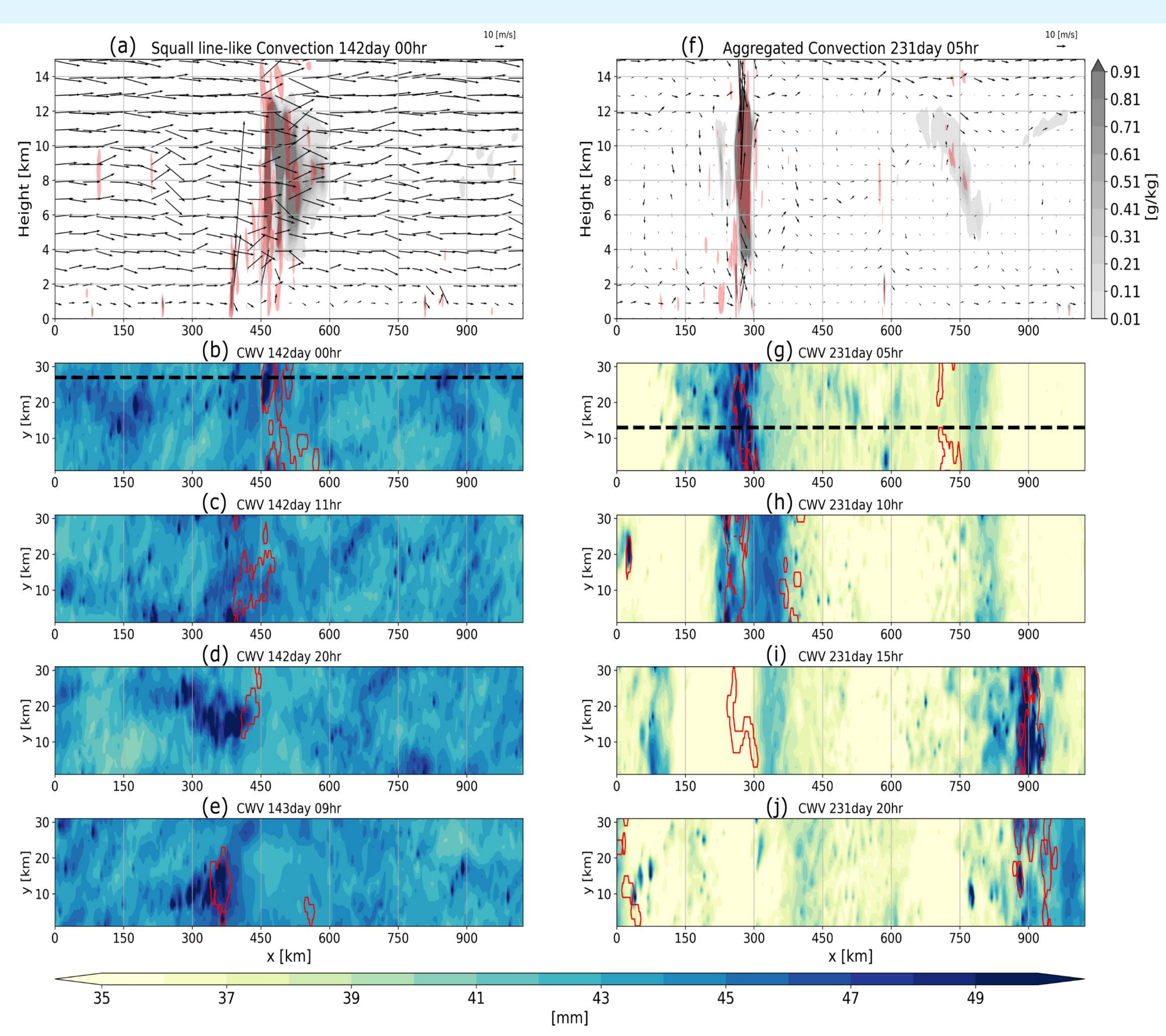
VVM (Wu et al., 2019) is used for its ability to capture circulations associated with thermal forcing. The horizontal domain size is 1024x32 km^2 with a 2 km resolution, and lateral boundaries are doubly periodic. We apply 130 vertical levels from the surface to 26 km with a constant 200 m resolution. The simulation is initialized by 5 m s^{-1} westerly, and other details can be found in the RCEMIP protocol (Wing et al., 2018).

3. QBO-like Oscillation in VVM



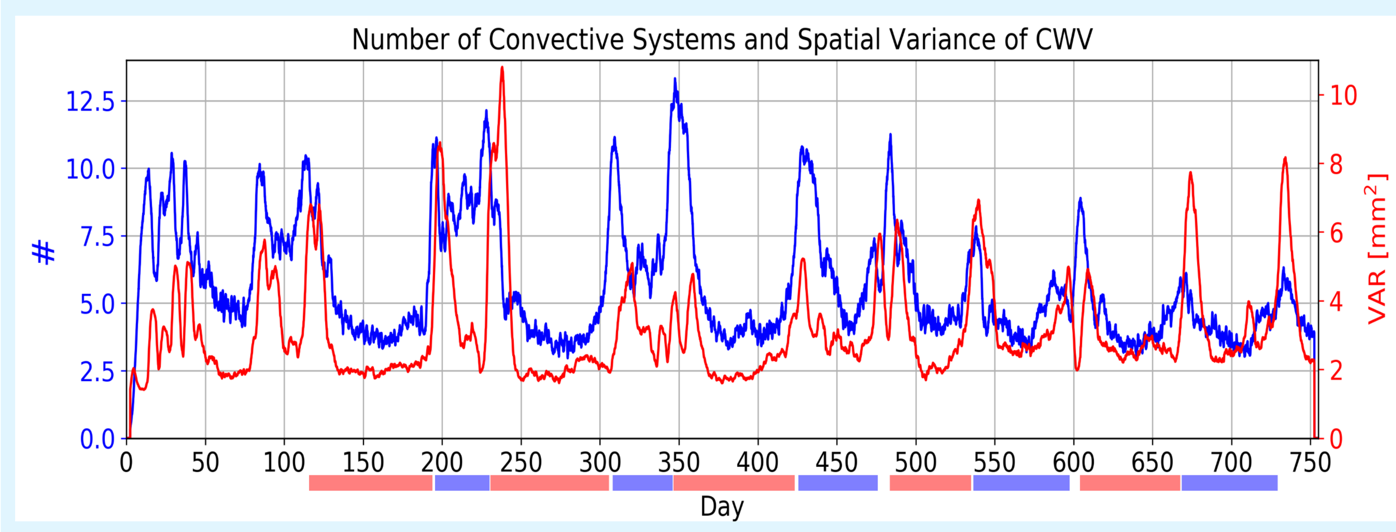
In VVM, QBO like-oscillation develops with 3 asymmetric periods and then becomes more symmetric. In the asymmetric period, the westerly phases have stronger strength and persist longer compared to the easterly phases. We found that column water vapor is higher in the westerly phases, while the atmospheric column is drier during the easterly phases. On the other hand, low-level wind shear is stronger in the westerly phases of the asymmetric periods. The weak wind shear in the lower level and dry environment in the easterly phases are crucial for the asymmetric periods.

4. Different Types of Convective Systems



Convective systems can be divided into two types: squall-line-like convection and aggregated convection. The squall-line-like convection develops in the westerly phases with the stronger low-level wind shear and wet environment condition. The aggregated convection appears in the easterly phases with weak low-level wind shear. When the aggregated convection develops, the domain spatial moisture difference increases. The different types of convective systems would contribute to the asymmetric QBO-like oscillation in VVM.

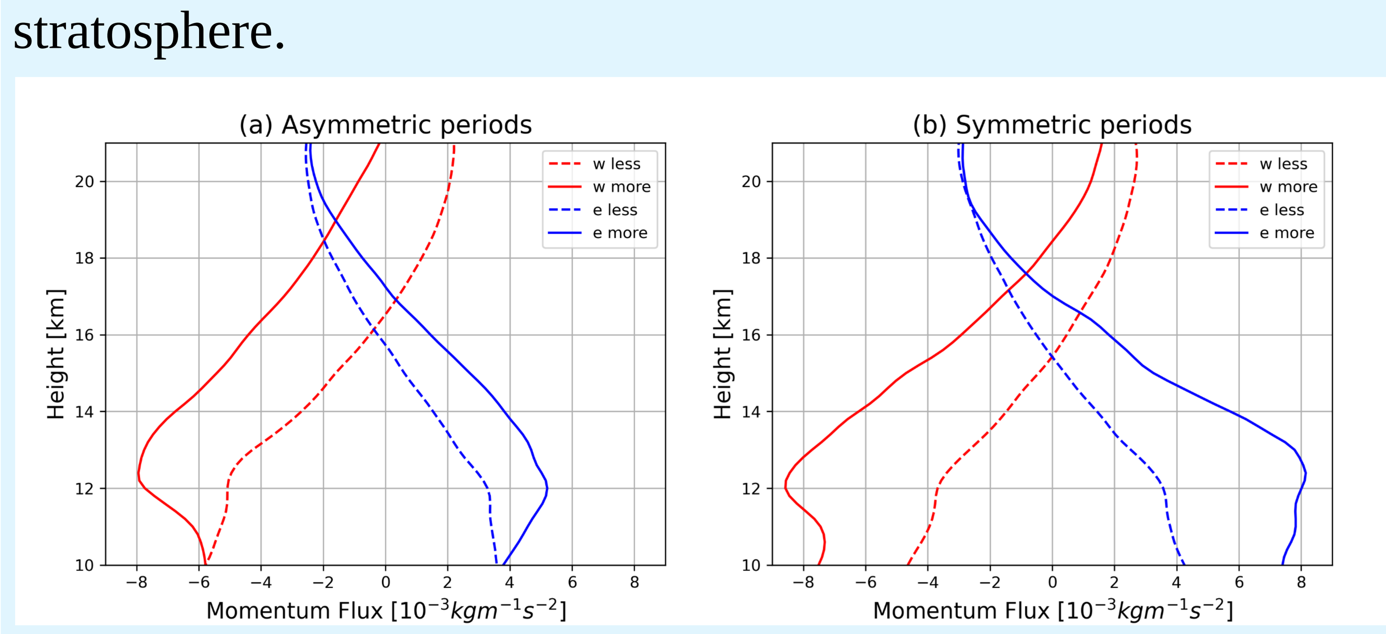
5. Momentum Budget



The number of convective systems significantly increases when the aggregated convection develops, which accompanies the growth of the spatial moisture variance. Therefore, we analyze the momentum budget for the domain-averaged zonal wind:

$$\frac{\partial \bar{u}}{\partial t} = -\frac{1}{\rho_0}\frac{\partial \rho_0 \overline{u'w'}}{\partial z}.$$

We sample the profiles of the lower stratosphere momentum transport based on the number of convective systems. The profiles show that the momentum flux with more convective systems (aggregated convection) is larger than that with fewer ones (squall-line-like convection) in both asymmetric and symmetric periods. The result suggests that the aggregated convection type can enhance the momentum flux in the lower stratosphere.



4. Future Works

- The difference in the wave momentum transport will be further investigated via spectrum analysis.
- Types of convective systems can change with the domain aspect ratio (Bui et al., 2019), so the sensitivity of convective systems to the different domain sizes will be examined.
- The change in surface temperature can also influence the convective structures, which could impact the interaction between troposphere and lower stratosphere.

Reference

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